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PRELIMINARY INVESTIGATIONS OF THE GEOGRAPHIC APPLICATIONS OF HO--ETC(U)

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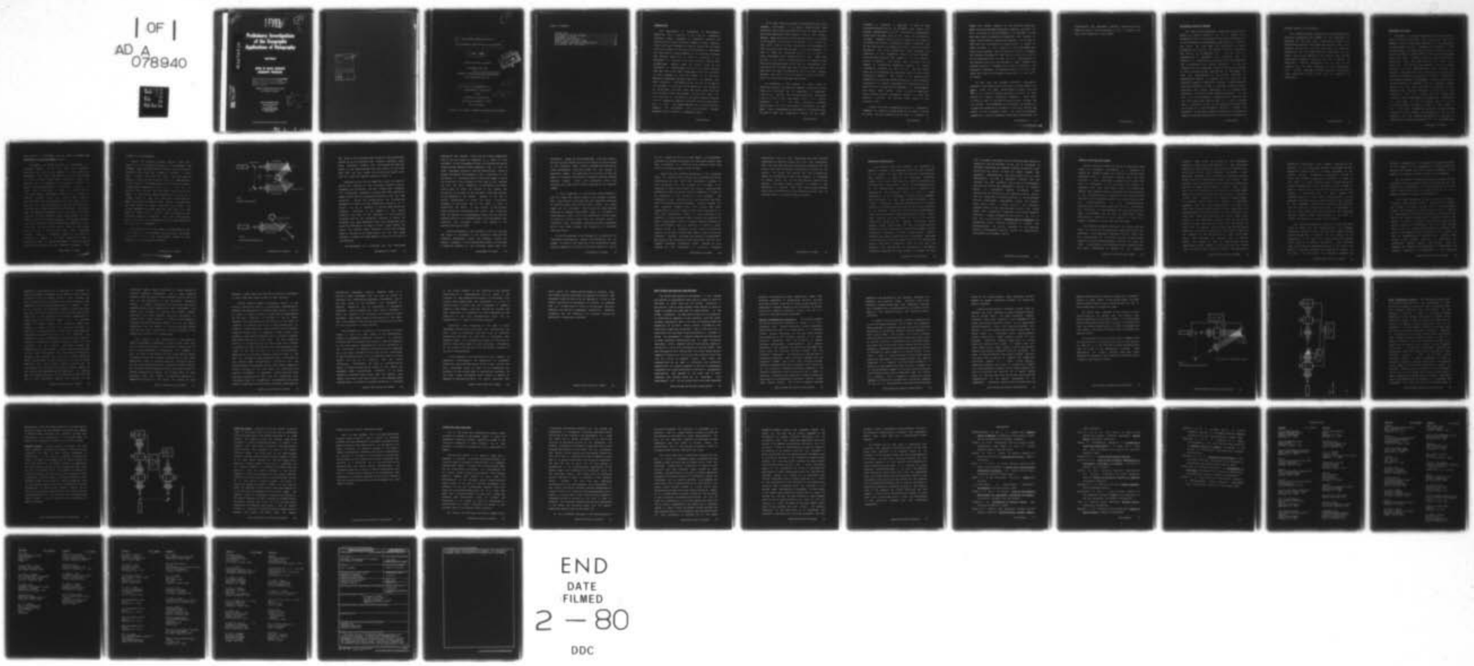

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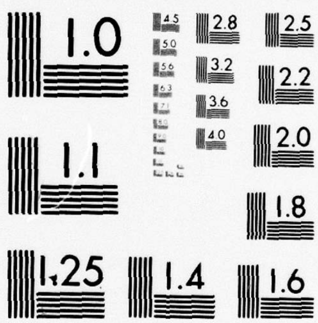
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Preliminary Investigations of the Geographic Applications of Holography

Final Report

OFFICE OF NAVAL RESEARCH
GEOGRAPHY PROGRAMS

CONTRACT NUMBER N00014-67-A-0103-0033
TASK NUMBER NR 389-164

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(6) PRELIMINARY INVESTIGATIONS OF

THE GEOGRAPHIC APPLICATIONS OF HOLOGRAPHY,

(9) FINAL REPORT.

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INTRODUCTION

The application of automation to enrivonmental geographic data collection is creating an information explosion which threatens to completely inundate and paralyze even the most efficient systems for data analysis. Faced with such tremendous volumes of data as are now being collected relevant to the spatial arrangements of phenomena over the earth's surface, methods of data storage, retrieval and analysis which are at least as efficient in the management of the data as the data collection devices must be developed. Indeed, given the current state of the techniques of geographical analysis, it is highly doubtful that more than a very small percentage of the data collected in such programs as the 1970 Census or by the Earth Resources Technology Satellite ever will be examined more than cursorily. The problem is one that has to be seen at the extremes. At one end, is the problem of the detection of significant variation when the cycles range from less than seconds to more than decades. On the other end, lies the magnitude of the scope of the data collection devices that are capable of sampling the entire surface of the earth acre by acre. The problem becomes one of identifying and isolating the differences and similiarities between phenomena half an earth's circumference apart.

It is clear that an attitude of indifference can not be assumed. Continually, it is being demonstrated that variations exist above and below the scale of human activity which have important effects upon all life on this planet, whether these variations be the long term cycle of ice ages or the diurnal fluctuations of the winds. The problem is that until tools to detect the changes in the extremes of the environment have been created, it will be impossible to know if there are variations occuring that do affect the human environment either beneficially or not. Thus, the problem to be faced in the analysis of the masses of new data being made available is the one of transcending the limitations of the scale and scope of normal human activity, that level for which the analytical tools are most sharply defined, and moving on to the study of realms of activity which up to now only have been conjectured.

An examination of the capacity of normal modes of scientific analysis portrays the inherent limitations of the traditional approaches for the management of geographic information. Consider the following examples. The normal 1:24,000 United States Geological Survey 7 1/2 minute topographic map, it has been estimated, contains approximately 1.0×10^{6} bits worth of information on each sheet. This is approximately the amount of information that the average human can effectively analyze at any given

instance in reaching a decision. A 1024 by 1024 microdensitometer scan in 32 different gray levels will produce approximately 1.0×10^7 bits worth of information, pretty near the upper end of the level of professional analysis. However, this is only the middle of the range of the analytical ability of sequential digital computers and at the lower end of the capability range of parallel digital processors. The standard 4-band ERTS image increases the complexity of the information handling problem by another order and about exhausts the capability of the parallel digital processors. The normal home television set is capable of transmitting tremendous volumes of signal information operating at the 1.0×10^8 bits per second level and far surpassing the analytical speed of the largest conceivable computer. This level is the beginning the capabilities of parallel optical processing. The throughput limitations of optical processors are limited only by the speed with which images can be generated for analysis(Bray and Jacobs, 1965, p.677). Thus, in terms of analytical power, parallel optical processing appears to offer the greatest potential for handling these masses of new geographic data.

Standard geographic methodology provides a theoretical framework to address problems posed at all levels of scale and scope. Optical processing would make it possible to

extend the channel capacity of the available analytical modes improving and amplifying data handling abilities so that variations in the environment at the extremes of scale and scope could be detected and phenomena that operate at those levels could be studied and analyzed. It may well be that there are no variations of significance to humans at these extremes or that within the human environment such wide ranging analyses yield no meaningful results. However, the possible existence of such significant variation should not be overlooked until at least the basic descriptions of the phenomena sensed at the extremes are made. However, the question arises as to whether it is wise to continue to use procedures developed for problems stated at the 1.0×10^{6} level when faced with problems on the order of 1.0×10^{10} or larger.

In many ways this problem represents a new age of discovery, where questions on the order of "what where?" are asked. After the basic descriptions are made it will be possible to advance to asking analytical questions of "why where?" and making predictive statements. With ever-increasing stress on the world's environmental systems and the greater interdependence of the nations and peoples, it is even more essential to be able to effectively monitor the status of the spaceship earth. The massive throughput capability of optical processing techniques when applied to

environmental and geographic analysis perhaps may be the means by which it will be possible to live in harmony with the finite resources of this planet.

PRELIMINARY RESEARCH PROGRAM

The goal of this preliminary investigation has been to assess the current state of the art in optical data processing with an eye towards the potential contributions of this technology to geographical data handling. Chiefly, the focus has been upon the applications of laser holography, as related to the storage, retrieval, analysis, and display of geographical data. This has lead to a consideration of geographic data structures and the potential of holography as a storage medium and analytical tool in conjunction with digital computers. It was not intended that new techniques of optical analysis be invented or hybrid digital-optical applications be developed, but that the applicability of the current technology to geographical anlysis in general and the needs of the sponsoring agency in specific be assessed. Some experiments have been conducted in order to evaluate selected optical processing and display techniques and to juxtapose some procedures that have not been combined heretofore. It was felt that it was necessary to demonstrate the relative ease with which holography might be used in a simply equipped optical laboratory, as well as the sophistication that could be achieved in a state-of-the-art facility. Further, the direction of continued research and application through the improved interface between optical and digital processing is

pointed towards by this project.

This research project originally was proposed while the principal investigator was a member of the Department of Geography at the Ohio State University, Columbus, Ohio. Considerable assistance and advice was obtained from Prof. Stuart A. Collins, Jr., of the Department of Electrical Engineering and the Electro-Science Laboratory at Ohio State. Prior to the awarding of the contract, the principal investigator accepted a position with the University of Washington, Seattle, Washington, and the bulk of the research work has been conducted at that institution. Prof. Collins continued his participation in the project under subcontracts to Ohio State from the University of Washington.

HOLOGRAPHY--A PRIMER

Holography is a kind of photography that uses coherent laser light to 1) record the three dimensional nature of objects, and 2) utilize more completely the resolving power of photographic emulsion. Holography was invented in 1948 by Denis Gabor, a British physicist who was trying to find a way to increase the magnification of the electron microscope (1948 and 1949). Gabor's invention came to be called a "hologram," after the Greek word "holos" which means whole, i.e. Hologram--the whole message. After his initial discovery and some experimentation which verified the concept, holography fell into disuse because of the lack of a reliable and practical source for coherent illumination, the necessary element in holography. In 1963, two engineers at the University of Michigan, Leith and Upatnieks (1964), working with the brand new laser, a convenient source of coherent light, revived holography to show that it was practical. From this initial work has flowed many extensions and the development of mathematical formulations for holography as well as various forms of optical processing based on the laser. Today, the laser ranks as one of the most powerful new scientific devices, perhaps second only to the computer, and holography is one of the simplest, yet most powerful applications of the laser. A comprehensive scientific discussion of the characteristics

and methods of holography can be found in Goodman, An Introduction to Fourier Optics, (1968).

Holography, like almost all forms of photography, is a two-step process. In the first step, the hologram is recorded, that is the film is exposed and then chemically developed. The second step consists of using the hologram to reconstruct the original scene. Holographic images are recorded by the encoding in a photographic emulsion of an optical interference pattern. The pattern is formed by two light waves interfering in space. In order that a consistent spatial interference pattern be made during the exposure, coherent light from a laser is used. Coherent light basically may be understood to be light waves in which any part of the waves maintain a constant relationship to any other part across the entirety of the waves. This means that the phase and amplitude of all light waves in coherent light are in unison reflecting their concentration in very narrow bands of the energy spectrum. Furthermore, coherent light waves maintain a fixed relationship between any point along their path and any other point. That is, they proceed essentially in a parallel form over great distances diverging only in a miniscule amount from the source of illumination. Indeed, it is often necessary to use a collimating lens to spread them wider in order to provide illumination sufficient for the complete coverage of the

objects to be holographed.

During the recording process coherent light from a laser is used to illuminate the object of the hologram. The coherent light reflected from the object, such as the light reflected from a flash gun, is made to interfere in space with a second beam from the laser. The second beam is usually derived from the first by means of beam-splitter. In that region of the space where the two beams are crossing a photographic emulsion is placed as in figure 1. The emulsion then records the interference pattern of the two beams. The interference pattern recorded on the film is a complex series of dark and light lines--light where the amplitudes of the interfering waves combine constructively and dark where the waves counteract each other. The distance between any typical dark and light line is on the order of about half a micron, hence a film with a high resolution emulsion is required. This very fine-grained, black and white film is developed in the normal manner and the first step is completed.

The reconstruction of the image is accomplished by the reintroduction of the coherent reference beam. The series of very fine lines in the interference pattern of the hologram act as a diffraction grating.

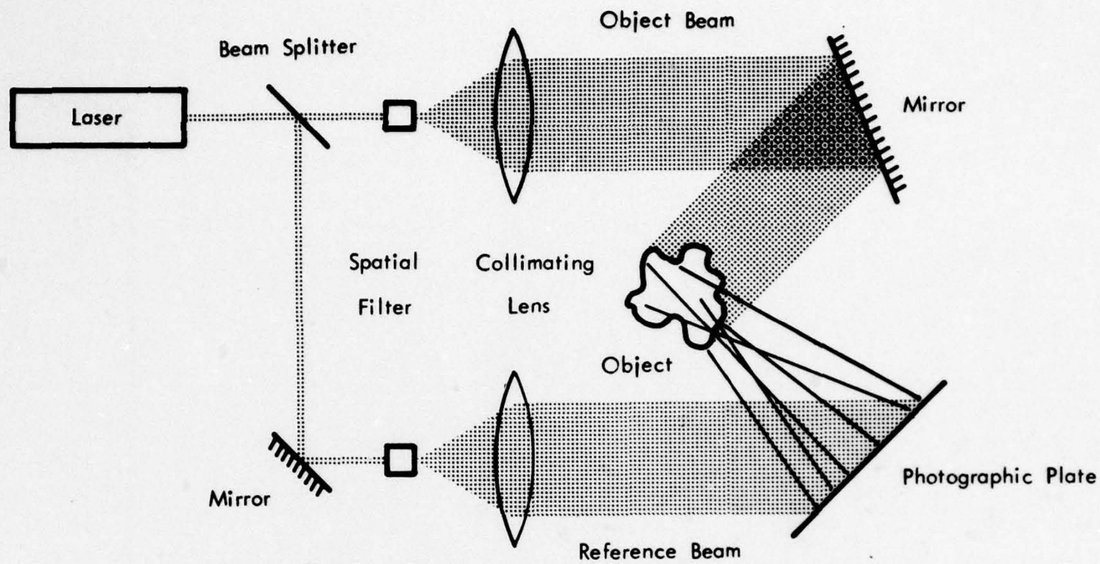


Figure 1

CREATING THE HOLOGRAM

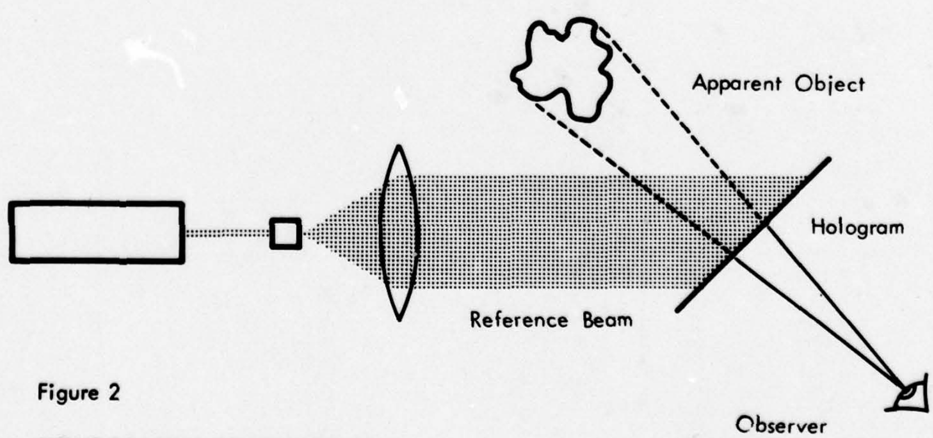


Figure 2

HOLOGRAPHIC RECONSTRUCTION

the light of the reference beam is bent by this diffraction pattern so as to reconstruct the original reflected light wave. Therefore, looking into the hologram one sees the object via the reconstructed light wave exactly as one would have seen the real object via the reflected object light with full depth and complete parallax, figure 2.

Depending on how the two beams were caused to interfere during the creation of the hologram, different types of holograms can be created. The most conventional hologram, the transmission hologram, is formed when both interfering beams impinge upon the photographic emulsion from the same direction. During the reconstruction the transmission holograms acts upon the light transmitted through it as in figure 2 so as to generate a virtual image behind the hologram. Variations in the geometry of the taking situation can lead to the formation of other types of holograms such as the reflection hologram in which the hologram acts upon reflected rather than transmitted light during reconstruction to cause a virtual image behind the plate, the focused image hologram in which the hologram plate is included in the image space, and the real image hologram in which the image appears to hang out in front of the hologram.

The advantages of a hologram over the traditional

photograph are several. First, the full three dimensional form of the real object as observed in a field of view subtended by the holographicy plate is preserved and may be viewed without special optical apparatus such as red and green anaglyphic glasses or optical stereoscopes. Unlike a normal photograph, the hologram is not a recording of the variations in reflected light as gray-tone images in which the direction of the incidence of the light is not recorded but only the total intensity. In holography, the object beam is used to probe the surface of the object, the variations in the paths of the two beams create the encoding of the geometry of the object. Because of the use of optical interference to record the scene, it is merely necessary to reintroduce one of the beams in order to reconstruct the other. If one returns to the original taking scheme and reintroduces the object beam reflecting from the object to the photographic plate, one can view the reconstruction of the reference beam in the same manner that reversing the situation allows the viewing of the reconstructed object beam.

A second advantage of the hologram is that by a varying the angle of incidence of the reference beam with the recording photographic plate, and thereby, varying the spatial frequency of the interference pattern of the plane or spherical waveform of the reference beam, many full

holographic images may be interspersed. Since the lines of the diffraction pattern do not fully occupy the entire space of the emulsion, there exists in between the diffraction lines considerable unutilized space for the storage of additional images. One needs only to be careful to vary the angle of incidence sufficiently to prevent crosstalk between adjacent images. Using such procedures, thick film holograms have been used to record some 300 to 400 seperate images.

A third advantage of the multiple image hologram is that the random data access format of the hologram provides more ready access to the data than the sequential structure of microform media which must be search before the proper image can be retrieved. The the multiple image hologram need only be indexed to the proper angle of incidence to simultaneously recall all of the information in that frame. It should be further noted that the hologram yields a relatively high information packing rate which approaches and in many cases exceeds the capacities of microform recording media.

A fourth advantage of the hologram is its potential for information preservation. Because the information for all images is stored in all sections of the photographic plate, physical damage to a portion of the plate destroys a little

of all images and not all of some images. The holographic plate may be dropped and broken, but the broken pieces each will reconstruct in a field of view related to their size all of the original images stored in them.

Despite the many inherent advantages of the hologram, there are several major difficulties associated with their construction and use. One of the fundamental problems is that associated with the creation of the image. It is necessary to have a very stable and nearly vibration-free platform, as well as quality optical components, in order to be successful in the creation of the hologram. The potentially high startup costs of such equipment may deter many from venturing into holography. Optical systems are now available however which will provide some basic capabilities in a price range no more costly than that of a fine 35mm photographic camera. A second problem is the necessity of using coherent light to record the image and at least monochromatic light of a sharply defined frequency to view the hologram. Thus, in addition to having a basic optical bench, it necessary to have a laser of reasonable quality and at least a metal vapor lamp in order to view the hologram. Thirdly, the images are generally monochromatic and usually red, the spectral line associated with the most commonly available helium-neon laser. Because of this problem all the advantages of selective frequency

enhancement, such as that associated with color infrared photography or density slicing, are lost with holography. Some work has been done with multicolor holography, but the results have been inconsistent and primarily limited to two colors. The fourth and perhaps the most disconcerting aspect of a holographic image is the tendency of holograms to appear grainy due to the ever-present coherent light speckle. This image quality problem is related to the reflection of coherent light from non-polished surfaces which causes interference in the reflection and can not be overcome easily in directly viewed holograms.

GEOGRAPHIC APPLICATIONS

The question that this research has attempted to address is whether those advantages that holography presents can be brought to bear upon the problems of geographical data handling. A survey of the geographic literature reveals that there have been only scattered references to the potential of holography. Even in the comprehensive work of the International Geographical Union Commission on Geographical Data Handling, there is only a brief description of the holographic process and the statement that "holography has many applications"(Tomlinson, 1972, p.452). Geographers have made considerable use of optical processing in investigating the use of the Fourier transform in the spectral analysis of spatial patterns (MacDougall, 1970; Barton and Tobler, 1971; McCullagh and Davis, 1972). Some interest has been shown in the use of optical correlation techniques for pattern recognition work. Wingert (1973) demonstrated the use of parallel optical processing in the application of the Weaver-Goodman optical correlation technique in photo interpretation. Rayner, Golledge and Collins (1971) did use a holographic technique in the analysis of spatial patterns but only for storing the phase of the fourier transform. None of this work has addressed the capabilities of holography as an optical processing technique for image storage or display. An area

with geographic overtones that has recieved some attention, especially from the military, is the use of holograms in automated navigation and guidance systems (Kilpatrick, 1969; Burton and Clay, 1972). It does not appear however that geographic considerations ever have played a role in these developments. The area of geographic interest that has received the most attention and in which the holographic applications are the most developed is the use of coherent optics in engineering mapping procedures. These applications are typified by the pioneering work of Mikhail and his associates at Purdue University in the development and use of holographic stereomodels (Glaser and Mikhail, 1970; Kurtz, 1971). A major force in the continuing research effort in this area has been Leighty at the United States Army Engineering Topographic Laboratories Research Institute. A superb statement of the state of the art in this area is to be found in Coherent Optics in Mapping, the proceedings from a meeting organized by Leighty and Balasubramanian and jointly sponsored by the American Society of Photogrametry and the Society of Photo-optical Instrumentation Engineers (1974).

SPATIAL DATA--FORM AND FORMAT

Before one can consider the nature of holographic data system for geographic information, it is necessary to examine the general classes and categories of spatial data. Geographers like to distinguish spatial data from data utilized by other scientists by emphasizing the fact that they are interested in the occurance and behavior of phenomena over space and through time. This means that whereas some scientists may be concerned about the variation in the characterisitics or behavior of some portion of the real world, the geographer couples this concern with one for the interrelationship of such phenomenological characteristics with those associated with the distribution and interaction of the phenomena over space and also with time. The phenomena may be seen as essentially static distributions existing at given moments in time or as dynamic processes in action over time and space.

The simplest conceptual structures for spatial data are those that relate to the dimensional characteristics of the phenomena. Point geographic phenomena then are those that are characterized as as existing, occuring or having been measured at a particular definable location in space and time. Extensionally, such phenomena have no dimensions and are mainly interpreted as incident at the specified

location. Many things are treated as point phenomena; however, in reality only the existence of some individual specimens or the occurance of some activity or behavior at a given point are true point geographic phenomena. Linear geographic phenomena are conceived as conditions existing along a line or as interactions between two points. Such phenomena are one dimensional in that something extends from one point in space towards another or exists along a path such that its location can be specified by a single number denoting its position within the lineal frame of reference. Traffic along a highway or the neighboring between members of different social groups are examples of geographic phenomena that have been conceptualized as linear. The third form of spatial data relates to those things that are conceptualized as having extension in two directions, i.e., areal data. There are relatively few things which occur simply in two dimensions; however, there are many things which exist over space and for which the designation of areal data is useful. Census tracts, land use and zoning categories, political jurisdictions, and property rights are all examples of the partitioning of space on an areal basis. These phenomena are basically seen as existing within the bounds of some two dimensionally variant description of their extent. On the other hand, the fourth form of spatial data, volumetric, reflects the variation of

phenomena in three space. Thus, a means is provided for the analysis of the continuous variation of phenomena as with atmospheric pressure which is present everywhere at the earth's surface. Furthermore, enumerations carried on within data collection areas can be treated as a count of the number of things existing within a sample and can be handled volumetrically in the same manner as the volume of water in a tidal rush or the volume of material in a terrain surface. A distinction must be drawn between the conceptualization of the spatial characteristics of the geographic phenomena and the identification of the location of that phenomena. Often there is confusion over the fact that the positional information relates to measurement in two or three spatial axes and one temporal axis. Whereas, the data elements mustbe distinguished on the basis of further information as to kind, rank or amount.

Many spatial phenomena are active at levels other than those at which they are conceptualized. For example, automobile accidents which are most often viewed as being point phenomena are in reality the end product of the conjunction of at least one linear process with another point, linear or volumetric phenomenon. Linear features like a tide line are conceptualized also as one spatial form when it is actually represent the operation of a second set of forms. In this case, the interaction between two

volumes. Consequently, it is necessary to be aware not only of the nature of the phenomena as it actually exists in reality, but cautious as to the biases introduced in the capture and recording of data related to the phenomena.

Any new system for handing geographic phenomena must be interfaced with the existing methods and techniques for the storage and manipulation of such information. It serves well to look at the nature of geographic reality as it is sensed, encoded, recorded, and represented.

The primary perception of spatial reality by humans is related to their senses, in that a successiion of stimuli are allowed to course through them as the individuals changes their location in space and time. Thus, a feeling is developed for the extent and dimensions of the world, as well as the relative organization of phenomena within that world. In order to better understand the nature of the world, a variety of technological aids have been devised which assist in sensing and recording the variations that occur in the dimensions and the extent of this reality as well as phenomenological characteristics. Chiefly, these devices allow greater precision in specifying the differences between sensory observations. Take, for example, the problem of the measurement of temperature. The simplest observation of temperature is the subjective

statement of the condition of an individual in relation to their environment, statements on the order of "It's freezing in here," or "It's a scorcher today." A more refined, but still subjective set of statements are those relating to the comparison of the sensible temperatures of objects. Thus, it is possible to distinguish between ice cubes that have just come out of the freezer and a pot that has come off the stove and to rank accordingly the sensible temperatures of other objects in relation to these. It is not possible however to specify exactly the differences among such objects. In order to do this, it is necessary to resort to some form of instrumentation. Chiefly, the liquid expansion thermometer has been relied upon for this function. The calibration of such thermometers against objects of known or theoretical temperatures provides relative scales for the assignment of more precise differences between the temperatures of given objects. Contact sensing devices such as the liquid thermometer and heat sensitive electronic detectors, are perhaps the third most common measuring device created after the mass measuring scale and the volume measuring cup. These contact sensing devices may be instrumented for continuous or discrete interval sampling of the variation in phenomenological temperature, or readings may be recorded manually. It is important to note that the use of such information implies the reduction of the

continuous analog values presented by these devices to discrete numerical annotations. Such a data recording process allows the entry of many different forms of error as well as the possibility of the well-known Heisenburg effect. A number of procedures for non-contact sensing of temperature have been created which allow measurement from within near distances to sensing from greatly removed positions, i.e., remote sensing. Relying on the ability of cryogenically cooled sensors to detect minute changes in long-wave infrared radiation, devices such as the Barnes thermograph and the Bendix IR scanner have been created which provide either analog film or digital readouts of the temperature patterns of an imaged scene.

With respect to the consideration of the range and scope of geographic information, it will be seen that data can be coded and recorded in a wide number of ways, even for such a simple phenomena as temperature. For example, in just one study a data system could be called upon to handle information as diverse as manual observations of sea water temperature taken by discrete sampling, continuous logs of air and ground temperature from a land-based weather station and thermal infrared images recording the spatial extent of surface temperature variation. All of these forms of data collected with one object in mind--the analysis of temperature variation in and around the action of some

phenomena under study, yet they are all basically different in their forms and format as well as their accuracy.

Another important aspect of geographic reality is the manner in which that reality is represented. Representation involves the permutation of recorded data through a series of steps in order to create a useful form of presentation for the data. Primarily, the problem is one of taking recorded data and creating a structure for it such that its integrity is preserved and its use is facilitated, that is, creating a data structure. Data structures may be formally organized things such as elaborate, random access disk systems or very simple procedures such as drawing a diagonal line across the top of a card deck. The most important function of a data structure is that in some way or another it prevents the data from falling into disorganization which leads to the loss of part or all of the information. Additionally, it provides a means by which the user of the data can find all of that information that is pertinent to the problem under consideration. Ordinarily, for the representation of geographic reality most people immediately think of the map as the sole means for portraying the spatial arrangement of phenomena. Indeed, maps and other map-like organizations of data into two dimensional data structures such as orthophotos, stereomodels, and actual physical models are very efficient and useful techniques for

representing geographic reality. However, there is a variety of other techniques that are just as useful in recording and representing geographic information. One of the most common is the gazeteer. This represents an ordered, sequential list of coordinates of geographic phenomena. Tariff schedules and time tables represent a means for reporting the structure of a network of linear phenomena. Tide tables record the variations of the water mass with respect to the terrain and indirectly can be used for the calculation of tidal currents.

The preparation of a graphic or the printing of a table however is only the final aspect of the representation problem for geographic phenomena. Data as it is initially collected must be organized and stored in some form amenable to the final modes of representation, but not necessarily in the final mode. For example, the coordinates of a gazeteer may be initially recorded in this form, but the coordinates of map information which are to be portrayed later in a flat graphic also may be in numerical form and stored accordingly. Furthermore, the data as collected may be global in nature and may not be related to the locale and phenomena under consideration. Therefore, it is often necessary to extract from a large data set smaller, more cogent ones that relate more directly to the problems under consideration. In general, the data collection is followed

by the entire problem of the reduction of the recorded information to a comprehensible form or cipher in the language of the communication medium to be utilized. This process often necessitates the application of a set of classificatory criteria and the assignment of symbolic ciphers to the classes. Once the enciphering process has been completed, it is necessary to allow some means for the generation of the final representation which may be accomplished in a number of different manners.

Hopefully, this discussion of the ways in which geographic reality comes to be known has demonstrated the vast scope of activities and the range of potential information that could be used with a holographic data storage system. It is possible to conceive of situations in which it would be necessary to store geographic information at any stage of its use clear from the initial recording to the final representation.

As has happened in the application of the computer to geographic investigation, the application of holography potentially could proceed along similiar lines. On the one hand, holography could be used for the augmentation and expansion of the current modes of geographical analysis. On the other hand, holography might provide a method of approach to problems and means for asking questions that

would extend far beyond current modes of analysis. Thus, two broadly defined areas must be examined to identify what holography mught be able to do for geography. First, is the general application of holography to a variety of problems that are already known in terms of the storage, retrieval, analysis, and display of geographic information. Secondly, holography has the potential for providing totally new approaches to geographic problems.

DATA STORAGE AND ANALYSIS APPLICATIONS

The direct applications of holography to the storage and analysis of geographical data must be viewed in terms of the modes in which data can be stored. Basically, a distinction must be drawn between those methods in which no image is created and those that are image forming. In the former procedures, the data must already be in a numerical or coded form or amenable to such encoding. With the latter systems, geographical data in the form of graphics, maps and photos may be directly stored without translation into numerically coded data structures. Most of the work that is being done with non-image forming procedures is related to either the development of computer memories and peripherals or other electronic applications such as video recording. (Rajchman, 1970). Computer data storage devices capable of storing 1.0 x 10 10 bits retrievable at optical speeds have been proposed by Pohl (1974,p.346) and slower access devices capable of storing 1.0 x 10 13 bits are currently are in use with the Illiac IV computer (Gusik, 1974, p.24). Any advances that can be made in increasing the analytical capabilities of digital computer by the use of holographic procedures will prove beneficial in the end to geographical applications just because of the great use to which computers are already being put in geography. Such developments will not be covered here since they represent

primarily the extension of known capabilities rather than different approaches to geographical analysis. The area which bears greater potential for enhancing the repertory of geographical analysis methods is the integration of optical and digital computing techniques through the use of a variety of new image forming techniques.

Hybrid Digital-Optical processing The dichotomy between the optical and digital processing of imagery is a well-recognized fact. Optical processing is nearly instanteous and processes all parts of an image equally in a parallel format. Digital processing, on the other hand, provides only capability for the selective analysis of an image. Scientists concerned with the processing of images, including cartographers, photogrammeters, and computer scientists, have searched for methods and techniques that would allow the effective interface between the two processing techniques. The difficulty to date has been in achieving an effective cross connection between the two procedures (Vander Lugt, 1971). Until recently, the most effective procedures have been photographic and do not allow for any effective interactive analytical capability. The problem is essentially one of finding not just a means of producing a coherent light image from a digital record, but the creation of differentially translucent optical filters under digital control. The inverse procedure has been

hampered by the coarseness of the detectors available for measuring the resultant images. Therefore, most of the previously created systems have used cumbersome, non-real time procedures and are characterized by an overall lack of quality in the digital-to-optical and optical-to-digital interfaces.

A number of new and practical interface procedures are or may soon become available. One of these new procedures being developed by Nisenson, Feinlieb, and Iwasa at the Itek Corporation is the Pockels Read-out Optical Modulator or PROM crystal (1974). This crystal, a thin slice of bismuth silicon oxide, is electro-optically sensitive to that it may be written optically and erased at near electronic speed. The images are of sufficient optical density and the crystal possesses transmission characteristics adequate for the use of the PROM as a input image or as a optical filter. A blue light is used to record the image on the crystal and the duration of the image is long enough to permit the optical modulation of a coherent light beam shown through it. A device with such capabilities could be used to replace all of the photographic images in an optical analysis procedure with digitally driven optical modulators under the control of a computer. Such a capability coupled with optical detectors in the form of a sector and ring Fourier analyzer or and an x,y array detector, would provide the building

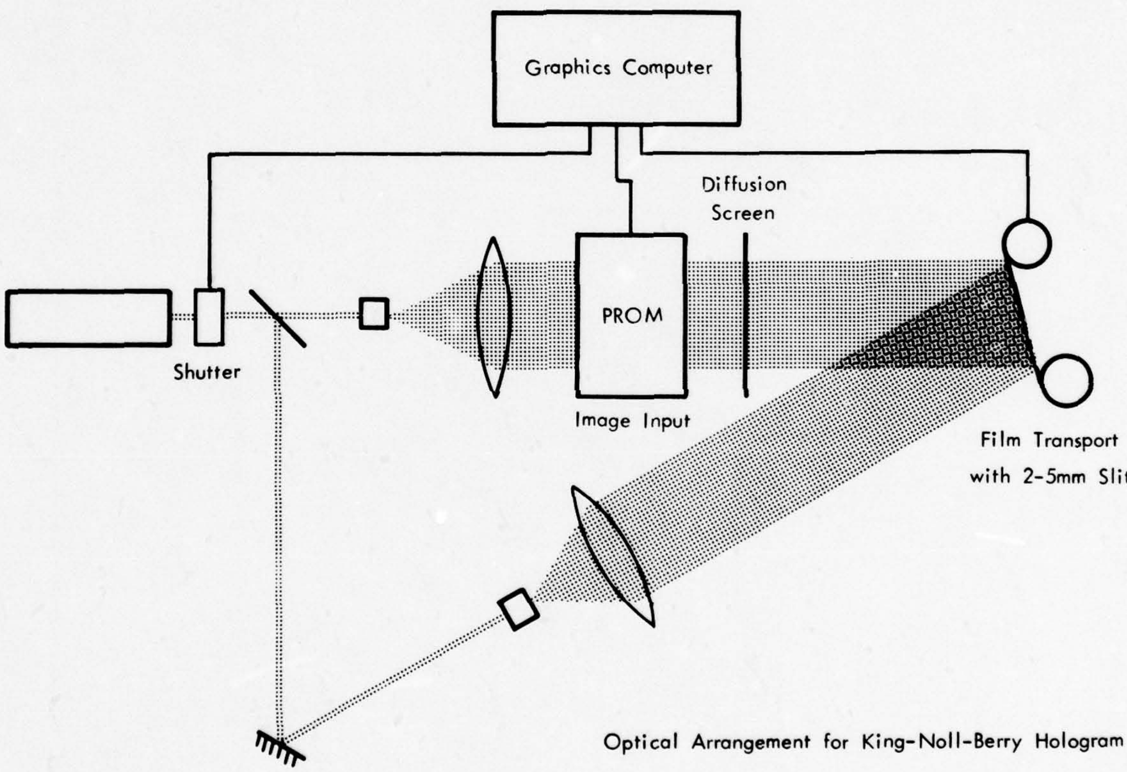
blocks for an electro-optical image processing facility capable of dynamic interaction between the digital and optical computers.

A hybrid digital-optical processing system would be composed two chief elements: an image processing computer and an optical bench. The image processing computer ostensibly would have available a full complement of the normal data storage facilities as well as the specialized digital-to-optical output and optical-to-digital input devices. It is anticipated that the PROM crystals could be driven either by a refreshable vector drawing graphics screen as well as by a raster scanning digital TV, thus providing interactive graphics capabilities to further extend the utility of the system. It appears that with three PROM crystal output modules most of the currently devised image analysis procedures could be performed. Two types of optical detectors also would be needed. One would be a sector and ring device for sampling the symmetrical diffraction pattern of a simple Fourier analysis. Thomasson, Middleton, and Jensen of Recognition Systems, Inc., have developed a detector with 32 wedges covering one-half of the optical power spectrum and 32 equally spaced rings on the other half which will allow a fairly accurate interpretation of the spatial frequencies of an image(1974). Information derived from the sector and ring

detector would be used to construct spatial and correlation filters in other PROM's in the Fourier plane. The other optical detector would be an x,y array detector for use in the re-quantizing of the optical image.

The second major component of the system is a stable optical bench for the optical train and coherent light source compatible with the PROM crystals. It is anticipated that the most useful system would include servo-controlled lens and optical module mounts, such that the alignment and fine tuning of the optical processor could be achieved under program control.

The application of such a hybrid optical computer would be limited only by the creativity and skill of its operators in applying it to the multitude of image processing tasks that are faced in the geographical sciences. Three applications are readily apparent based upon proven experimental procedures: three dimensional graphics, spatial filtering, and image correlation.



Optical Arrangement for King-Noll-Berry Hologram

Figure 3

THREE DIMENSIONAL COMPUTER GRAPHICS

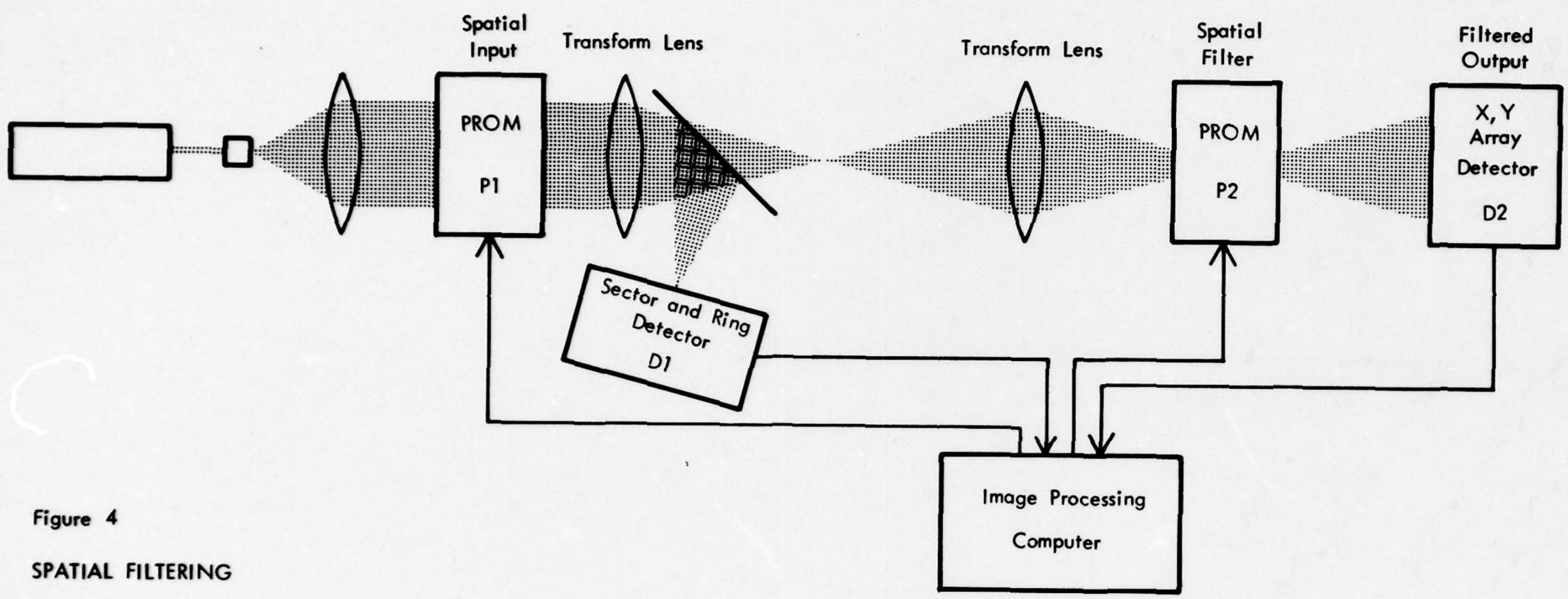


Figure 4

SPATIAL FILTERING

Three dimensional Graphics the PROM module could be used as the image output device for the construction of King-Noll-Berry holograms in conjunction with a relatively simple film transport mechanism (King, et.al.,1970). The KNB hologram is basically a series of very small holograms presenting the view of some perspectively projected three dimensional image. A number of views of the object varying by only a few degrees of rotation along the x axis of the hologram or by a few degrees of elevation along the y axis are recorded as normal transmission holograms. Presently, it is necessary to create these seperate views as microfilm from a computer output on microfilm device or film of a graphics terminal. Due to the photographic transfer of the images from the computer to the hologram taking situation, the process is arduous and time-consuming. Replacing the photographic steps with a PROM crystal would make the King-Noll-Berry hologram a useful and practical display procedure, figure 3. By such a technique, it would be possible to generate a computer graphic output that appeared to the viewer to be truly three dimensional in nature. By judicious selection of the increment for the film transport and the use of a slit rather than a series of small cells, a three dimensional animation could be achieved. This effect would be accomplished by the movement of a continuous KNB holographic film across the line of the reference beam. A

modification of the film holder mechanism to provide angular variation rather than film movement would allow the creation of multiple image holograms from digitally encoded data facilitating the dissemination of up-to-date maps and graphics for holographic navigation and guidance systems.

<u>Spatial Filtering</u> spatial filtering techniques are used quite commonly in geographical research in order to isolate elements on the basis of their spatial frequencies or orientations. In the optical arrangement illustrated in figure 4 an image is introduced into the system through the first PROM crystal P1. Its Fourier transform is detected by the sector and ring device D1 after the beam has been split by the half-silvered mirror. The computer can analyze the information derived from the sector and ring sensor in order to construct a spatial filter in the second PROM P2 so as to eliminate either certain orders of spatial frquencies found in the original image or particular orientations of spatial frequencies. The result of the spatial filtering can be read in an x,y format compatible with the original input by the array detector D2. Such a system in an interactive mode would provide a highly flexible tool for the analysis of spatial patterns.

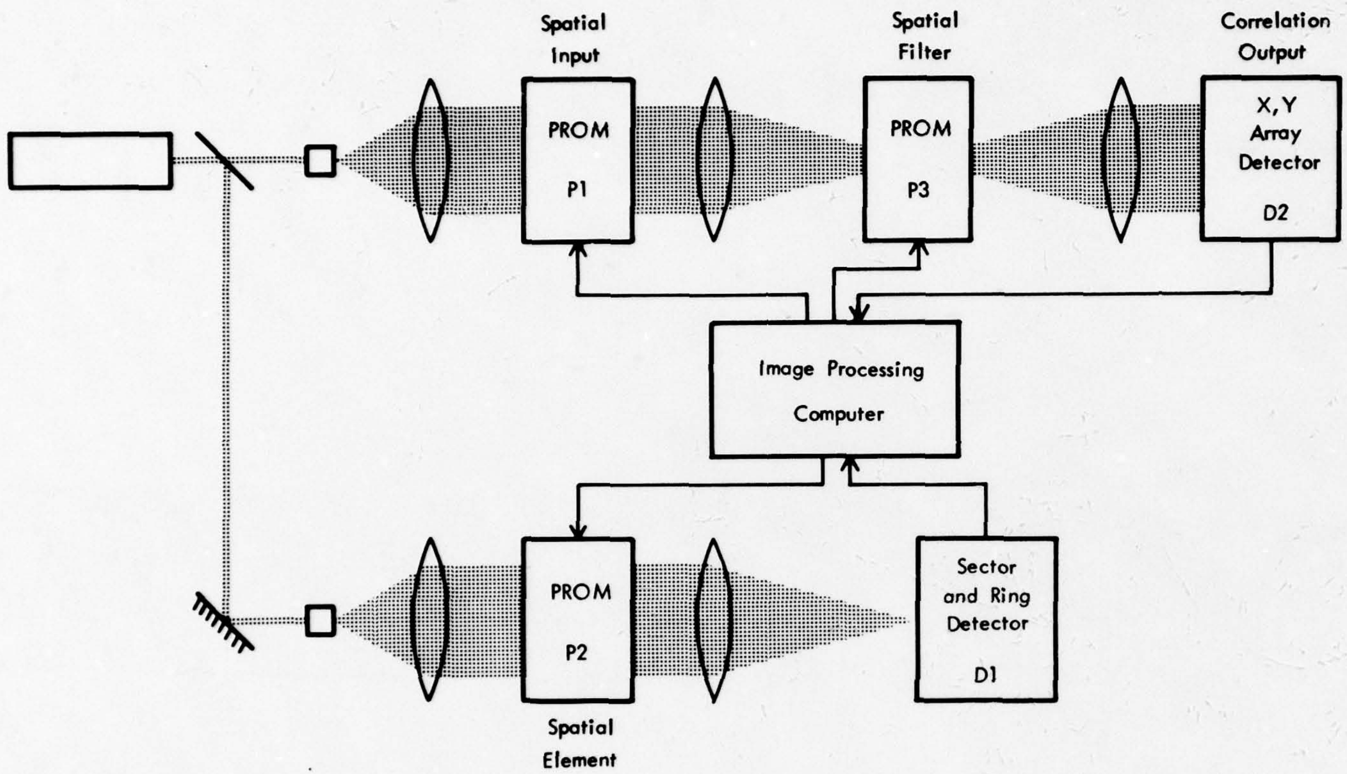


Figure 5

PATTERN RECOGNITION-CORRELATION

__Image Correlation__ carrying on from the spatial filtering idea, it can be seen that if the filter that is interjected into the optical path is the Fourier transform of an image element, its location within the original image can be discerned in a photo interpretation mode. In figure 5, the coherent light beam is split and part of the beam proceeds down an optical path identical to that of the spatial filtering setup. The other part of the beam proceeds through a similiar spatial filtering setup; however, instead of an image being presented by the PROM crystal P2 for analysis, a spatial element of some form, is presented and its Fourier transform is detected by the sector and ring device D1. From the Fourier transform of the spatial element, a filter is constructed for the original image and introduced into the optical path by the second PROM crystal P3 in the spatial filtering scheme. The points of correlation between the spatial element and the original image are detected as bright spots by the array detector D2 in x,y positions corresponding to the original image. The computer could be programmed to change the orientation of the spatial elements in order to achieve the highest overall correlation between the filter and the original image. Conceivably, the computer could create a bank of spatial filters of a variety of different spatial elements and the computer could select from among these for element

identification in a photo interpreation mode.

There is some evidence that this image correlation procedure could be used to solve a variety of non-image problems including mathematical programming problems such as spatial allocation and classification. In the abstract, the image correlation and analysis problem is not unlike a number of geographical problems involving the classification of entities on the basis of their measured similiarities. There appears to be no reason why the multi dimensional data pertinent to a particular set of entities could not be converted into some analog optical representation. The programmed selection of spatial filtering combinations could lead to a classificatory ordering of the observations. Many mathematical programming problems are structured similiarly and their solution constraints could be expressed as fixed spatial filters.

ASSOCIATIVE DATA STRUCTURES

One of the things that holography has caused a number of people to consider is the general manner in which the holographic recording process operates as a model for the storage of information in other contexts. One of these contexts is related to epistemology and the organization of memory.

Consider what happens in an abstract sense when a hologram is created. A regular, predictable pattern, the reference beam, is allowed to interfere with an irregular, unpredictable pattern of light, the relfected object beam, and this interference is recorded. The reintroduction of the regular pattern allows the recreation of the irregular pattern. However, the inverse is also true; the reintroduction of the irregular pattern reconstructs the regular image. In the case of optical holography, this procedure is not very interesting. However, there is no reason why the reference beam could not be of some form other than a regular spherical or plane wave. Indeed, the reference beam theoretically could be filtered and transformed in any manner as long as it was possible in reconstruction to exactly duplicate the nature of the reference beam in the original taking situation.

Now consider the mind which also may be thought to use

a holographic interference technique for the storage and manipulation of information. The entire education process may be seen as one involved in the development of a large and useful set of mental holograms to be used in the recalling of information as well as its processing. For example, throughout an individual's experience with written language many examples of the letter "a" are encountered. Most persons are so familiar with the general structure of this letter that it is possible for them to identify it even when it is grossly distorted or only partially discernable. How does the mind do this? Part of this process is accomplished in the psycho-physical manipulation of the sensory image in its transmission to the sensory store and the short-term memory. The broken parts of line may be filled in mentally in order to generate a more complete figure. However, the mind can work remarkable transformation on the basic geometry and relationships of the figure, performing extreme, nonlinear permutations of images in order to fit them into some comprehensible form of reality. It may be that in this initial process somewhere a holographic filter is utilized by the mind in order to transform the irregular, unpredictable patterns represented by the broken and distorted figure into the regular, predictable pattern known as the letter "a".

In this situation, analogous to the reconstruction of

the optical hologram, the retrieval is performed in is parallel. That is a given stimuli is taken as a whole ad the referent is retrieved as a whole simultaneously. The mind has the additional capability of being able to feed information back into itself to further refine its understanding and to add information together in order to recognize words, phrases, sentences, and ideas.

All of this makes for an interesting excursion but how does it relate to geography? general information storage systems as they now exist work on simple, direct input and retrieval. Fundamentally, information is stored in a data structure with some reference scheme related to known external characteristics of the data or internal addressing procedures and through the use of the reference scheme the information can be directly recalled. As an example, one might have a set of health statistics for each county in the United States randomly stored on a disk and for which directories have been built which index counties by states. It is a simple matter to access the data for the jth county of the ith state by referencing the directory for the ith state and offsetting by j to find the address the record for the jth county. Regardless of how complex such a directory scheme or record format may become, systems like this one only provide directly the information that was stored within it. That information is returned only in the simple

sequential manner in which it was originally stored. The access to the data may be greatly expanded by the introduction of spatial retrieval techniques, but the information still only comes back sequentially within the context of the imposed organizational structure. This kind of system is good for record keeping but poor for analysis. For example, if one wishes to study the high incidence of heart disease then the file containing that information must be inverted on the basis of the information related to heart disease, and then specifically searched for those elements that could be defined as high. Such a system facilitates access to the information but it does not facilitate the development of higher undrestanding about the distribution. Consider, however, the concept of an associative data storage system where data is stored indirectly as a result of the presentation of the information to the system and is retrieved when information about the dimension of the problem under consideration is presented. In other words, in the example given above, the general terms in which the problem was defined, the high incidence of heart disease, would be used as regular pattern to be input to the data structure in order to affect the retrieval (Kugel, 1963). Meant by high incidence and heart disease. The digitial simulation of the functioning of an associative data structure is performed only with great difficulty and each

accession incurs considerable system overhead. The use of an integrated digital-optical processor with holographic memory units might make such a sophisticated system feasible.

The relevant use of this idea of associative data structures for geographic information systems is that they would allow attention to be directed towards to the structure of the problems rather than upon the manipulation of the data. In other words, instead of phrasing the data retrieval questions in very specific terms necessary for direct sequential access where it is possible to bypass important interrelationships in the data, the questions could be posed in general terms such that the associative data store would extract the most meaningful portion of the information from storage that was relevant to the problem. As the system was repeatedly used for similiar accession, it would learn analytical strategies suitable to the specific form of the analyses and further facilitate the data access. If this type of the machine were allowed to free-wheel such as the human brain, it might find relationships in the particular problems that were theretofore unsuspected.

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This report provides an introduction to optical holography and its applications in Geography. The nature of the holographic process is explained and its advantages and disadvantages are considered. The forms and formats of spatial data are examined it respect to the requirements for a holographic data storage systems. Digital-optical interfaces allow the creation of hybrid computing devices and three applications of these → next page

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to spatial analysis and data display are indicated. The relationship of holographic theory to associative data structures also is considered.